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Nuclear Power Plant

Dhiraj Ahuja1[1], Neeraj Ahuja[2]
[1]Department of Electrical and Electronics Engineering, YMCA University of Science and Technology, Faridabad, 121006, India
[2]Lovely Professional University, Jalandhar- Ludhiana G.T.Road, Near Chaheru, Railway Bridge-Phagwara, Punjab-144402(INDIA)
Emails: ddahuja8978@yahoo.com, nahuja30@yahoo.com

(Abstract) Nuclear power is the power (generally electrical) produced from controlled (i.e., non-explosive) nuclear reactions. Commercial plants use nuclear fission reactions. Electric utility reactors heat water to produce steam, which is then used to generate electricity. Sixteen countries depend on nuclear power for at least a quarter of their electricity. France gets around three quarters of its power from nuclear energy, while Belgium, Bulgaria, Czech Republic, Hungary, Slovakia, South Korea, Sweden, Switzerland, Slovenia and Ukraine get one third or more. Japan, Germany and Finland get more than a quarter of their power from nuclear energy, while in the USA is one fifth from nuclear. Among countries which do not host nuclear power plants, Italy gets about 10% of its power from nuclear, and Denmark about 8%.

Keywords Heavy water (D2O); BWR (Boiling Water Reactor); Pressurized Water Reactor; Modern Digital I&C System.

1. Main parts of nuclear power plant

Nuclear power plant consists of control rods which are made of steel containing a high percentage of material that can absorb neutrons, e.g. boron. The control rods are pushed into the core of the reactor. They control the amount of reaction and hence the amount of heat energy being produced. The nuclear reaction produces heat and that is carried away by the coolant. Typical coolants used are water, carbon dioxide gas, liquid sodium. Fast moving neutrons have their speed moderated by passing through a moderator. Typical moderators used are water, graphite or heavy water (D2O). Only neutrons of a fairly low speed can produce fission of the uranium nuclei. Steam produced in the steam generator passes to a steam turbine. The force of the steam jet causes the turbine to rotate. This is connected to a generator which produces electricity.

1.1. Nuclear fuel

Nuclear fuel is any material that can be consumed to derive nuclear energy. The most common type of nuclear fuel is fissile elements that can be made to undergo nuclear fission chain reactions in a nuclear reactor. The most common nuclear fuels are 235U and 239Pu.Natural uranium contains 0.7% 235U. This has to be increased to about 3% to be more useful in a nuclear reactor. When a neutron strikes an atom of uranium, the uranium splits into two lighter atoms and releases heat simultaneously. Fission of heavy elements is an exothermic reaction which can release large amounts of energy both as electromagnetic radiation and as kinetic energy of the fragments. A chain reaction refers to a process in which neutrons released in fission produce an additional fission in at least one further nucleus. This nucleus in turn produces neutrons, and the process repeats. If the process is controlled it is used for nuclear power or if uncontrolled it is used for nuclear weapons.

The following equation and the reaction as an example:

The equation :

235U + 1 neutron $\rightarrow$ 2 neutrons + 92Kr + 142Ba + ENERGY

The reaction:

1 = 2 + 92 + 142 = 236

Thus, it seems that no mass is converted into energy. However, this is not entirely correct. The mass of an atom is more than the sum of the individual masses of its protons and neutrons, which is what those numbers represent. Extra mass is a result of the binding energy that holds the protons and neutrons of the nucleus together. Thus, when the uranium atom is split, some of the energy that held it together is released as radiation in the form of heat. Because energy and mass are one and the same, the energy released is also mass released. Therefore, the total mass does decrease a tiny bit during the reaction [1]

2. Types of Nuclear Power Plant

There are following two types of reactors

2.1. Boiling Water Reactor

Boiling water reactor operates in as a fossil fuel generating plant. Water in the BWR (Boiling water reactor) boils inside the pressure vessel and the steam water mixture is produced and reactor coolant moves upward through the core absorbing heat. When the steam rises to the top of the pressure vessel, water droplets are removed, the steam is sent to the turbine generator to turn the turbine[2]. There is only one circuit with water at lower pressure so that it boils in the core at about 285°C. Steam passes directly to the turbines (Fig.1).

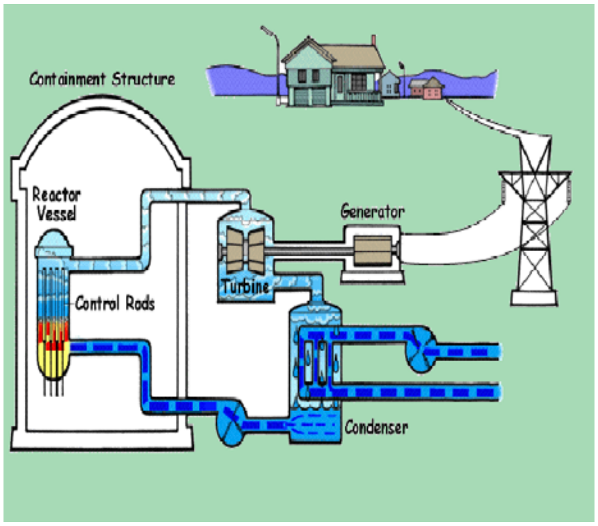

Figure 1. Boiling water reactor

2.2. Pressurized Water Reactor

PWR (Pressurized Water Reactor) differs from the BWR in that here the steam to run the turbine is produced in a steam generator. A pressurize unit keeps the water that is flowing through the reactor vessel under very high pressure to prevent it from boiling. The hot water then flows into the steam generator where it is converted to steam. The steam passes through the turbine which produces electricity. About 60% of the world's commercial power reactors are Pressurized Water Reactors (PWRs). The obvious advantage to this is that a fuel leak in the core would not pass any radioactive contaminants to the turbine and condenser (Fig.2).

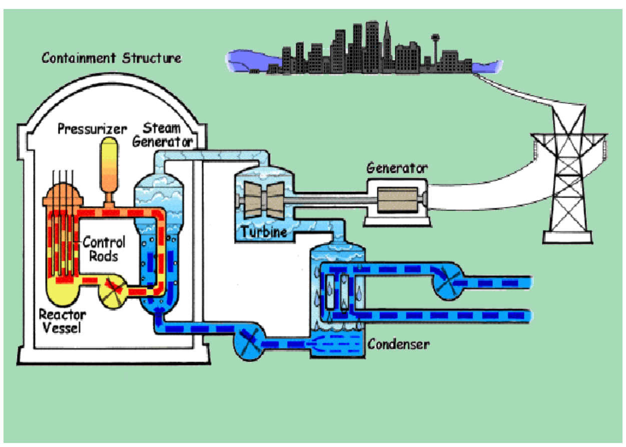

Figure 2. Pressurized Water Reactor

2.3. Improved Performance from Existing Nuclear Reactors

As nuclear power plant construction returns to the levels reached during the 1970s and 1980s, those now operating are producing more electricity.In 2007, production was 2608 billion kWh. The increase over the six years to 2006 (210 TWh) was equal to the output from 30 large new nuclear power plants. Yet between 2000 and 2006 there was no net increase in reactor numbers (and only 15 GWe in capacity). The rest of the improvement is due to better performance from existing units. In 2007 performance dropped back by 50 TWh due to plant closures in Germany, UK and Japan.

In a longer perspective, from 1990 to 2006, world capacity rose by 44 GWe (13.5%, due both to net addition of new plants and uprating some established ones) and electricity production rose 757 billion kWh (40%). The relative contributions to this increase were: new construction 36%, uprating 7% and availability increase 57%.

One quarter of the world's reactors have load factors of more than 90%, and nearly two thirds do better than 75%, compared with about a quarter of them in 1990. For 15 years Finnish plants topped the performance tables, but the USA now dominates the top 25 positions, followed by Japan and South Korea.

US nuclear power plant performance has shown a steady improvement over the past twenty years, and the average load factor now stands at around 90%, up from 66% in 1990 and 56% in 1980. This places the USA as the performance leader with nearly half of the top 25 reactors, the 25th achieving more than 98%. The USA accounts for nearly one third of the world's nuclear electricity.

In 2009 and 2010 nine countries averaged better than 80% load factor, while French reactors averaged 73%, despite many being run in load-following mode, rather than purely for base-load power.

Some of these figures suggest near-maximum utilisation, given that most reactors have to shut down every 18-24 months for fuel change and routine maintenance. In the USA this used to take over 100 days on average but in the last decade it has averaged about 40 days. Another performance measure is unplanned capability loss, which in the USA has for the last few years been below 2%[3].

3. Instrumentation in Nuclear Power Plant

The instrumentation and control (I&C) system

architecture, together with plant operations personnel, serves as the "central nervous system" of a nuclear power plant (NPP). Through its various constituent elements (e.g., equipment, modules, sensors, transmitters, redundancies, actuators, etc.), the plant I&C system senses basic physical parameters, monitors performance, integrates information, and makes automatic adjustments to plant operations as necessary. It responds to failures and off-normal events, ensure goals of efficient power production and safety and ensure safe and reliable power generation. Importance should be given for the projects involving the design, testing, operation, maintenance, licensing, operation, and modernization of I&C systems.

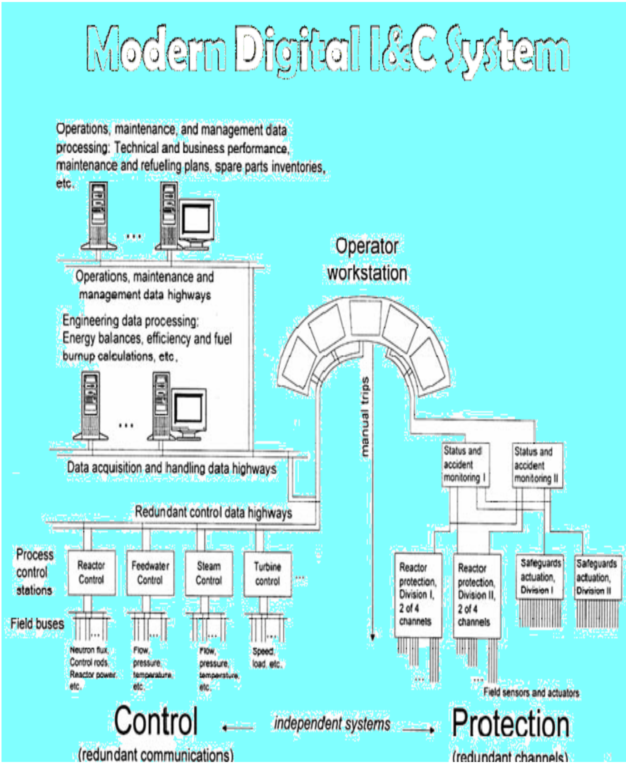

Figure 3. Modern Digital I&C System

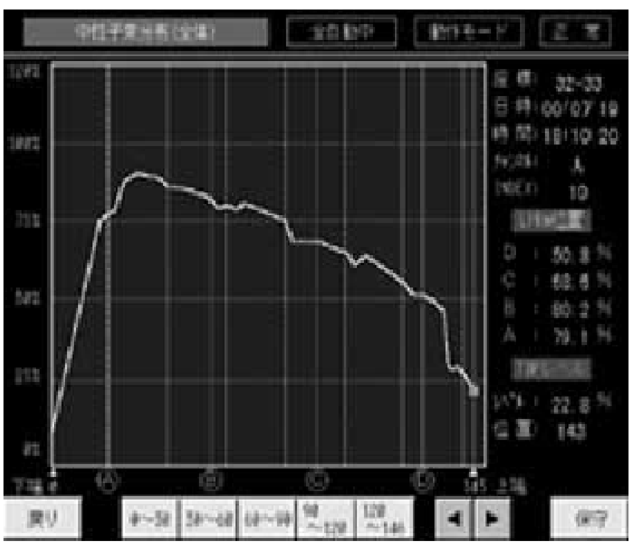

Figure 4. Reactor Monitoring System

3.1. Modern Digital I&C System

Blocks on the left given (Fig.3) represent the distributed control systems. These are the systems that are used to regulate plant conditions during startup, power operation, and shutdown. They are responsible for maintaining plant systems and components within their operating ranges, and they normally operate in a regulating mode. Redundant data buses are used to transport the large amounts of information typically handled in a large generating station. Lower level blocks on the left dedicated to the control of individual systems. Real-time control functions are executed in these dedicated modules. Blocks on the right represent the independent protection (safety) systems. These are responsible for detecting system failures and isolating or shutting down failed systems to protect the plant investment and the public health. System uses multiple channels in a voting scheme to trigger the isolation or shutdown action. A typical voting scheme uses a two-out-of-four logic according to which, if one of the four channels fails, the failed channel may be taken out of service for repairs, while still leaving the remaining channels to take action using two-out-of-three logic [4and5]. Thus, the system is single-failure proof. The use of two channels to trigger an action provides protection against unnecessary spurious trips (Fig.3).

3.2. Reactor Monitoring System

Reactor monitoring system is a particular feature of nuclear power plants, and is in the form of a neutron monitoring system for measuring neutrons within the reactor and a radiation monitoring system for measuring radiation within the plant. A neutron monitoring system is essential to core monitoring. To meet the need for improved maintainability and operability, Hitachi has completed development of a new series of this system using a color flat display based on a new compact controller. It has labor saving features like automatic gain calibration and a function for managing digital data of plateau characteristics by a personal-computer tool. Operation is also improved by using a flat display and digitizing measurement data simplifies data management (Fig.4).

4. Safety of Nuclear Power Plants

Safety is taken very seriously by those working in nuclear power plants. Main safety concern is the emission of uncontrolled radiation into the environment which could cause harm to humans both at the reactor site and off-site. There is a series of physical barriers between the radioactive core and the environment. The reactors are enclosed in heavily reinforced concrete which is 1.8m thick. Workers are shielded from radiation via interior concrete walls. A vacuum building is connected to the reactor buildings by a pressure relief duct. The vacuum building is a 71m high concrete structure and is kept at negative atmospheric pressure. This means that if any radiation were to leak from the reactor it would be sucked into the vacuum building and therefore prevented from being released into the environment. Design of the reactor also includes multiple back-up components, independent systems, monitoring of instrumentation and the prevention of a failure of one type of equipment affecting any other. Safety is also important for the workers of nuclear power plants. Radiation doses are controlled via the following procedures : The handling of equipment via remote in the core of the reactor, Physical shielding and Limit on the time a worker spends in areas with significant radiation levels[6].

5. Maintenance of Core Cooling

In any nuclear reactor cooling is necessary. Generally nuclear reactors use water as a coolant. Some reactors which cannot use water use sodium or sodium salts.

6. Control of Radioactivity

Control of the neutron flux is essential. If we decrease the neutron flux we decrease the radioactivity. Most common way to reduce the neutron flux is to include neutron-absorbing control rods. Control rods are very important because the reaction could run out of control if fission events are extremely frequent. In modern nuclear power plants, the insertion of all the control rods into the reactor core occurs in a few seconds, thus halting the nuclear reaction as rapidly as possible. In addition, most reactors are designed so that beyond optimal level, as the temperature increases the efficiency of reactions decreases, hence fewer neutrons are able to cause fission and the reactor slows down automatically.

7. Conclusions

Nuclear technology uses the energy released by splitting the atoms of certain elements. It was first developed in the 1940s, and during the Second World War research initially focussed on producing bombs by splitting the atoms of either uranium or plutonium.

In the 1950s attention turned to the peaceful purposes of nuclear fission, notably for power generation. Today, the world produces as much electricity from nuclear energy as it did from all sources combined in 1960. Civil nuclear power can now boast over 14,000 reactor years of experience and supplies almost 14% of global electricity needs, from reactors in 30 countries. In fact, many more than 30 countries use nuclear-generated power.

Many countries have also built research reactors to provide a source of neutron beams for scientific research and the production of medical and industrial isotopes.

Today, only eight countries are known to have a nuclear weapons capability. By contrast, 56 operate civil research reactors, and 30 host some 440 commercial nuclear power reactors with a total installed capacity of over 377,000 MWe (see table). This is more than three times the total generating capacity of France or Germany from all sources. Over 60 further nuclear power reactors are under construction, equivalent to 17% of existing capacity, while over 150 are firmly planned, equivalent to 46% of present capacity.

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